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RESEARCH MEMORANDUM

WING-DROPPING CHARACTERISTICS OF SOME STRAIGHT AND SWEPT WINGS AT TRANSONIC SPEEDS AS DETERMINED WITH ROCKET-POWERED MODELS

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RESEARCH MEMORANDUM

WING-DROPPING CHARACTERISTICS OF SOME STRAIGHT AND SWEPT WINGS AT TRANSONIC SPEEDS AS DETERMINED WITH ROCKET-POWERED MODELS

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SUMMARY

A lateral-trim change or wing dropping that involves a rapid change of lateral trim with Mach number has occurred on several rocket-powered models used in roll investigations at transonic speeds. The data reported herein demonstrate that straight wings with airfoil sections 9 percent thick or greater are susceptible to this wing dropping between Mach numbers of 0.9 to 1.0. Also, if the airfoil contour is not fair wing dropping may occur even for thin wings. Sweepback only partially relieves the problem of the 9-percent-thick wing in that at 45° sweep no trim change occurred, but at 30° sweep wing dropping occurred. Changes in aspect ratio have no significant effect on the wing-dropping phenomenon.

INTRODUCTION

A type of lateral-trim change known as wing dropping has occurred on several airplanes in the transonic speed range. For example, just before reaching $M = 1.0$ a wing will drop so that the application of large aileron deflections accompanied by considerable stick force is required. At a somewhat higher Mach number the airplane will return to trim. On slowing down the airplane, the same sequence of events happens in reverse.

This phenomenon of lateral-trim change, or wing dropping, has occurred in tests of several rocket-powered models used in the investigation of damping-in-roll characteristics by the technique reported in reference 1. The purpose of this paper is to present data on the effects of airfoil section, aspect ratio, and sweepback on the lateral-trim-change problem.

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SYMBOLS

$\frac{pb}{2V}$	helix angle of roll, radians
$\frac{pb/2V}{\delta_a}$	aileron-rolling-effectiveness parameter
δ_{a_T}	deflection of each aileron for trim, degrees
M	Mach number
M_D	Mach number at maximum out-of-trim helix angle
$\frac{t}{c}$	airfoil section thickness ratio, free stream

MODELS

The type of rocket-powered model from which the subject data were obtained, as described in reference 1, consists of a simple blunt-based fuselage to which various wing configurations are attached at the rear as the stabilizing surfaces in a three-wing arrangement. These wings were without ailerons and mounted with no intentional incidence with respect to the fuselage center line. The apparatus and technique used in this roll investigation are described fully in reference 1. The data presented are from the coasting period of the flights of the damping-in-roll models where the rolling velocity, or helix angle $\frac{pb}{2V}$, is recorded continuously throughout the flight. The data are essentially for zero lift flight. The various wing configurations reported herein are shown in table I.

RESULTS

For the lateral-trim curves presented, the level of the out of trim at subsonic speeds was adjusted to zero. This is a valid procedure as can be seen from the roll data reported in reference 2 for models with the wings set at angles of incidence to produce roll. These data show that the trend and bumps of $\frac{pb}{2V}$ against M are nearly identical regardless of the general trim level produced by the wing incidence. For the data presented the approximate Reynolds number range varied from 4.5×10^6 at $M = 0.85$ to 8×10^6 at $M = 1.4$ as described in reference 1.

Straight Wings

The trim helix angles for three rocket-powered models with wings of aspect ratio 3.7, no sweep, no taper, and NACA 65A009 airfoil sections are shown in figure 1. The lateral-trim change between $M = 0.90$ to 0.95 is severe, and some out-of-trim helix angles remained at supersonic speeds. An example of the inconsistencies of the direction of trim change is shown in this figure by the results obtained from tests of three models each having the same configuration; negative values of helix angle are shown to have been encountered with models 2A and 2C and positive values with model 2B. The average Mach number at maximum out of trim for the three models with 9-percent-thick wings is 0.93. The amount of each aileron deflection that might be required to hold the wings level is also shown in figure 1. These values of δ_{a_T} were obtained by utilizing the rolling-effectiveness characteristics of this configuration as reported in reference 3. The ailerons are one-half the exposed span and are simple sealed flaps with a chord 20 percent of the wing chord. The reference aileron-effectiveness tests were for 5° deflection and it is assumed that the $\frac{pb/2V}{\delta_a}$ is linear for small deflections. Therefore, the values of δ_{a_T} were determined as follows:

$$\delta_{a_T} = \frac{\left(\frac{pb}{2V}\right)_{\text{Out-of-trim}}}{\left(\frac{pb/2V}{\delta_a}\right)_{\text{Roll effectiveness}}}$$

A change in each half-span-aileron deflection of 4° required may be considered appreciable in view of the small helix angles encountered.

The effect of lower aspect ratio (3 as compared to 3.7) is small as shown in figures 1 and 2(a). Again the wing dropping is severe, occurring at an average $M = 0.89$ for the two models. The effect of greater wing thickness, 12 percent as compared to 9 percent of figure 1, is shown in figure 2(b). This wing with aspect ratio of 3.7 and with NACA 65A012 sections has a severe trim change occurring at $M = 0.89$ with the trim $\frac{pb}{2V}$ values approximately the same at subsonic and supersonic speeds.

Shown in figure 3 are the out-of-trim rolling characteristics of some nontapered straight wings with 6-percent-thick airfoil sections. Two configurations of aspect ratio 4.5, reported in reference 4, but differing only in section contour as a modified double wedge and

NACA 65-006, are shown in figures 3(a) and 3(b), respectively. The effect of section contour is such that, for the 6-percent-thick double-wedge section, wing dropping occurred at $M = 0.91$, whereas for the NACA 65-006 no wing dropping occurred. Also, shown in figure 3(c), no wing dropping occurs for wings of aspect ratio 3.7 with NACA 65A006 sections.

Sweptback Wings

The effect of sweepback on the lateral-trim-change characteristics of an untapered wing of aspect ratio 3.7 and of NACA 65A009 profile can be obtained by comparing figures 1, 4(b), and 4(c). Sweepback is shown to reduce the severity of wing dropping. The wing sweptback 30° suffered only mild wing dropping at $M = 0.95$; no wing dropping was noted for the wing with 45° sweepback. Tests of the wing of aspect ratio 3.7 and NACA 65A006 profile for 0° sweepback (fig. 3(c)) or 45° sweepback (fig. 4(a)) showed no abrupt wing-dropping tendencies.

Delta Wings

Shown in figure 5 are the out-of-trim rolling characteristics of three rocket-powered models with 60° delta wings of aspect ratio 2.31 with flat-sided or hexagonal sections of constant thickness which correspond to thickness ratios of 3 percent at the wing-body juncture and 9 percent at the tip end of the flat-sided portion. Wing dropping occurs near $M = 0.90$ on this 60° delta wing. This delta-wing configuration was also tested with half-delta tip ailerons by another rocket-powered model technique as reported in reference 5. Therefore, the values of trim aileron deflection δ_{a_T} required are presented in figure 5 as calculated by the previously described procedure. For this case of tip ailerons on the delta wing, the aileron effectiveness is large enough so that only very small deflections are required to hold the wings level.

DISCUSSION

From the results presented it can be noted that the important parameters that affect the wing-dropping characteristic are the sweep and the airfoil section.

Not only is the thickness important but the contour, or fairness, of the section is of importance. For the examples shown for straight wings with NACA 65A-series sections, 12- and 9-percent-thick wing dropping occurred, whereas for the ones with NACA 65A006 and 65-006 sections no wing dropping occurred, but the 6-percent-thick modified double-wedge section wing suffered wing dropping. The wing dropping of the modified double-wedge model probably originates from the sudden change in contour inasmuch as the section is thin and the trailing-edge angle is approximately the same as the NACA 65-series. In other words, if the thickness or contour of the airfoil section is such as to produce extensive separated flow when the wing is operating at transonic velocities a loss of lift will occur. The investigation of reference 6 shows, by means of schlieren photographs and pressure measurements, the effect of airfoil contour on the local flow conditions. These data show at high subsonic speeds a symmetrical 6-percent-thick double wedge to have unsymmetrical flow conditions and extensive separated flow rearward of the contour break, whereas for NACA 66-006 sections no unsymmetrical flow exists. Inasmuch as the local flow is sensitive to surface conditions, it is unlikely that a loss of lift will occur simultaneously on both wings.

From the results of the sweptback wings, wing dropping may be prevented on the NACA 65A009 section wings by a sweepback of 45°. Although sweeping this wing 30° did not prevent wing dropping, the motion was not as severe as for the straight wing.

When the airfoil section effects on the local flow at transonic speeds are considered it is apparent that the delta wings tested would experience wing dropping due to the thick tip and to the hexagonal section shape, but in the case of applying tip ailerons to this wing, the aileron effectiveness is very good (reference 5); consequently, only small trim aileron angles are required.

The occurrence of wing dropping and the Mach number at which dropping occurs for the various configurations and wing sections are summarized in table I.

CONCLUSIONS

From the data on the lateral-trim-change characteristics of several rocket-powered models, the following conclusions may be made:

1. Straight wings with thick airfoil sections, 9 percent or greater, were susceptible to wing dropping.

2. Inasmuch as wing dropping did not occur for a wing having the NACA 65A006 profile but did occur for a wing of 6 percent thickness of symmetrical modified double-wedge section, apparently due to extensive separation of the flow over the wing, it was concluded that an abrupt change in contour may bring about wing dropping.

3. For wings with NACA 65A009 sections, sweepback of 45° prevented wing dropping, but 30° sweep did not.

4. Changes in aspect ratio from 3.0 to 3.7 for an unswept wing of NACA 65A009 profile and from 3.7 to 4.5 for an unswept wing having a symmetrical section of 6 percent thickness were found to have no significant effect on wing dropping.

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REFERENCES

1. Edmondson, James L., and Sanders, E. Claude, Jr.: A Free-Flight Technique for Measuring Damping in Roll by Use of Rocket-Powered Models and Some Initial Results for Rectangular Wings. NACA RM L9I01, 1949.

2. Strass, H. Kurt, and Fields, Edison M.: Flight Investigation of the Effect of Thickening the Aileron Trailing Edge on Control Effectiveness for Sweptback Tapered Wings Having Sharp- and Round-Nose Sections. NACA RM L9L19, 1950.

3. Strass, H. Kurt: The Effect of Spanwise Aileron Location on the Rolling Effectiveness of Wings with 0° and 45° Sweep at Subsonic, Transonic, and Supersonic Speeds. NACA RM L50A27, 1950.

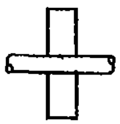
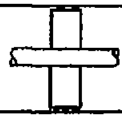
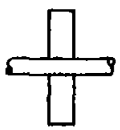
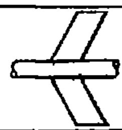
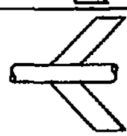
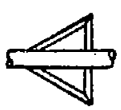
4. Dietz, Albert E., and Edmondson, James L.: The Damping in Roll of Rocket-Powered Test Vehicles Having Rectangular Wings with NACA 65-006 and Symmetrical Double-Wedge Airfoil Sections of Aspect Ratio 4.5. NACA RM L50B10, 1950.

5. Sandahl, Carl A., and Strass, H. Kurt: Comparative Tests of the Rolling Effectiveness of Constant-Chord, Full-Delta, and Half-Delta Ailerons on Delta Wings at Transonic and Supersonic Speeds. NACA RM L9J26, 1949.

6. Lindsey, W. F., Daley, Bernard N., and Humphreys, Milton D.: The Flow and Force Characteristics of Supersonic Airfoils at High Subsonic Speeds. NACA TN 1211, 1947.

TABLE I

WING CONFIGURATIONS

Configuration	Model	Airfoil section	Aspect ratio	Sweep (deg)	Body diam. / Wing span	Wing dropping	M_D (approx.)
	1A, 1B, 1C	NACA 65A006	3.7	0	0.191	No	----
	2A, 2B, 2C	NACA 65A009				Yes	0.93
	3A, 3B,	NACA 65A012				Yes	.89
	4A, 4B	NACA 65A009	3.0	0	.212	Yes	.89
	5A, 5B	[a]Modified double wedge $\frac{t}{c} = 0.06$	4.5	0	.181	Yes	.91
	6	NACA 65-006				No	----
	7	NACA 65A009	3.7	30	.191	Yes	.95
	8	NACA 65A006	3.7	45	.191	No	----
	9	NACA 65A009				No	----
	10A, 10B, 10C	Hexagonal tip, $\frac{t}{c} = 0.09$ Root at body, $\frac{t}{c} = 0.03$	2.31	60° delta	.226	Yes	.90

[a]Double wedge of $\frac{t}{c} = 0.0653$ at 50 percent chord modified to $\frac{t}{c} = 0.06$ by an arc tangent to contour.

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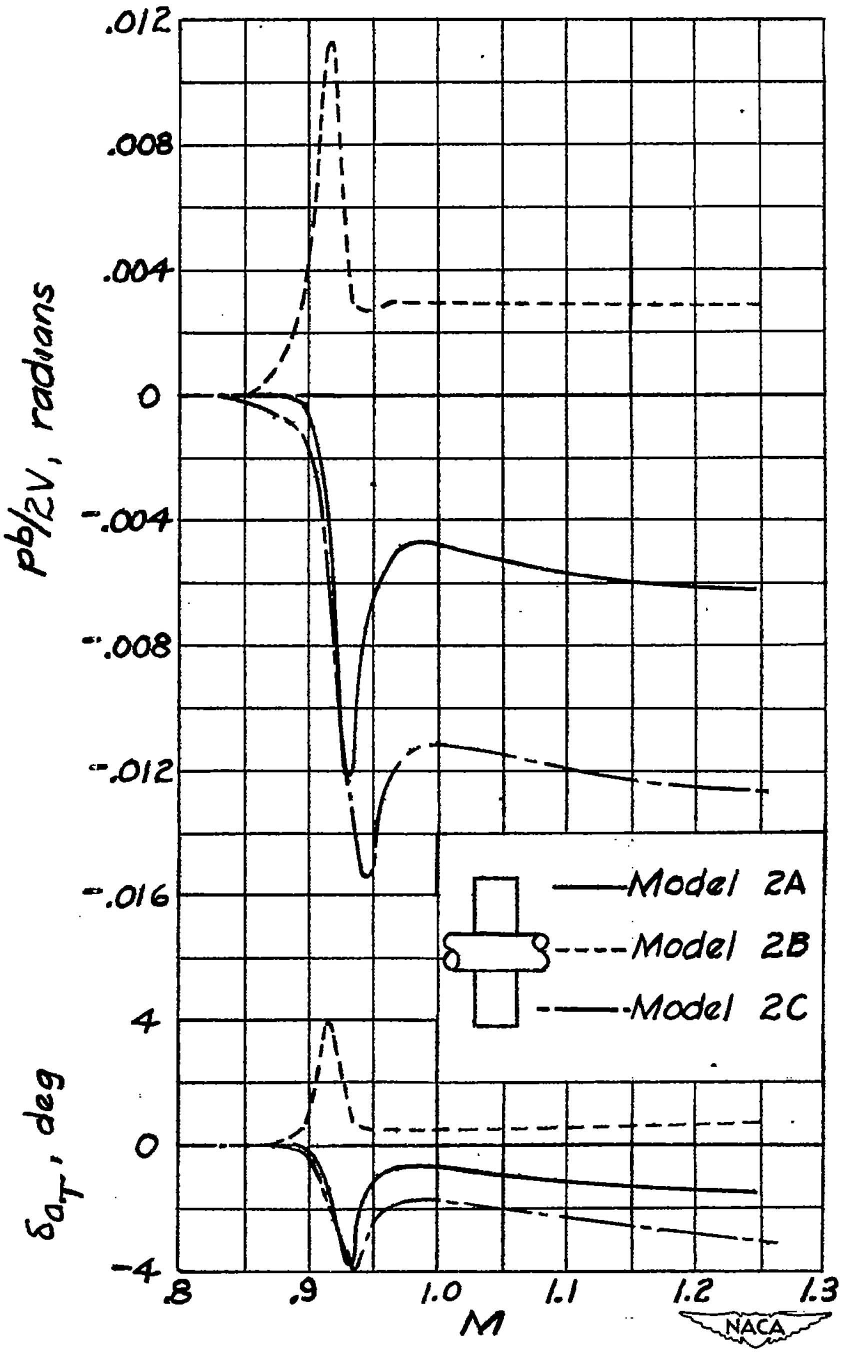
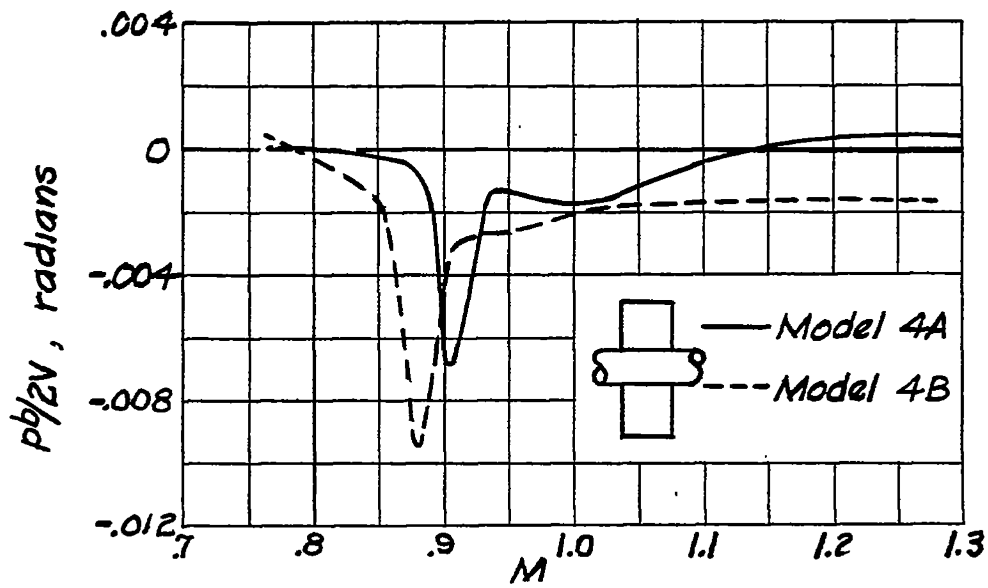
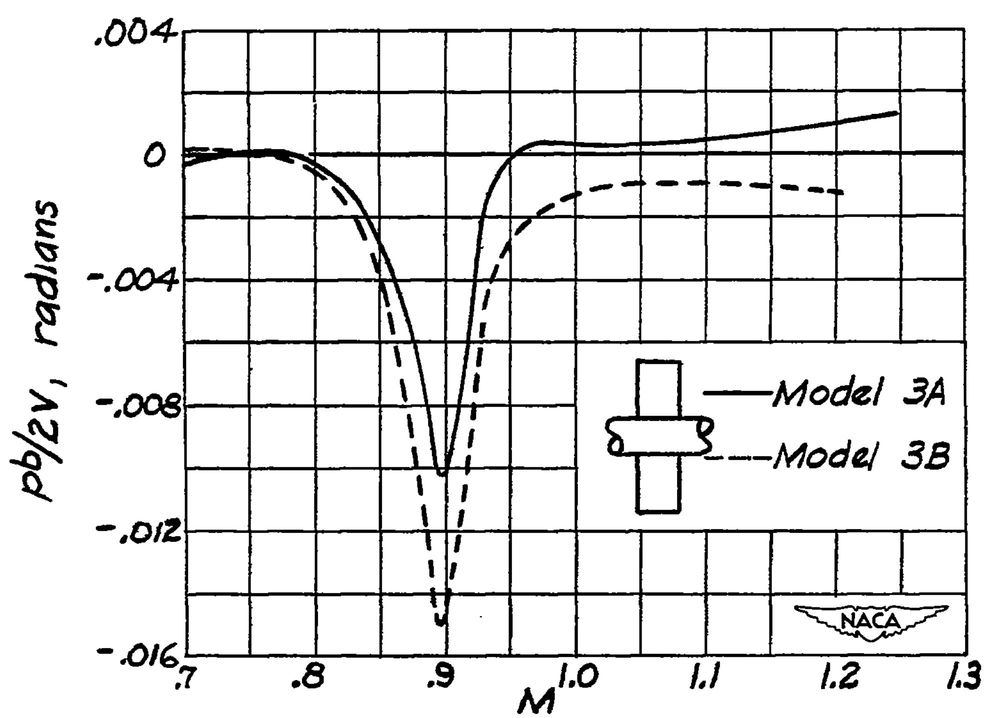


Figure 1.- Out-of-trim helix angles and trim aileron deflections required for models with wings of aspect ratio 3.7, no taper, no sweep, and NACA 65A009 airfoil sections. (The values of δ_{a_T} are estimated for half-span ailerons, reference 3.)

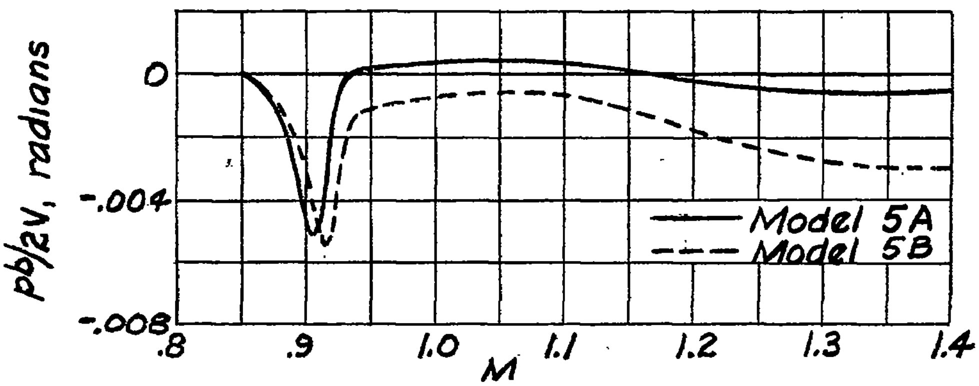


(a) Aspect ratio 3 and NACA 65A009 sections.

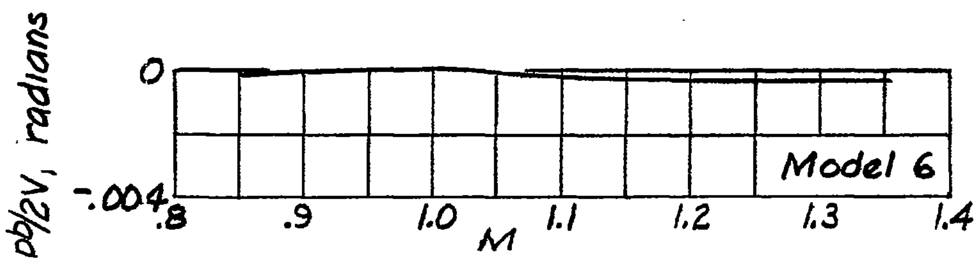


(b) Aspect ratio 3.7 and NACA 65A012 sections.

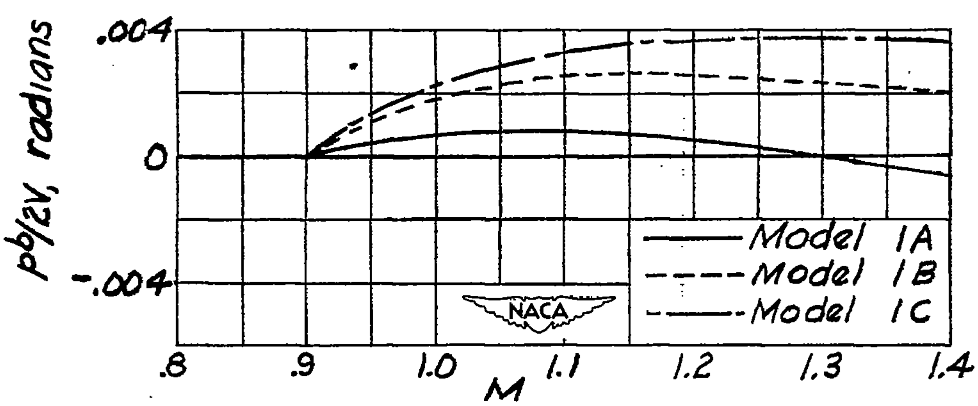
Figure 2.- Out-of-trim helix angles for models with straight nontapered wings for aspect ratios 3 and 3.7 and NACA airfoil sections 65A009 and 65A012.



(a) Aspect ratio 4.5 and modified double wedge, $\frac{t}{c} = 0.06$.

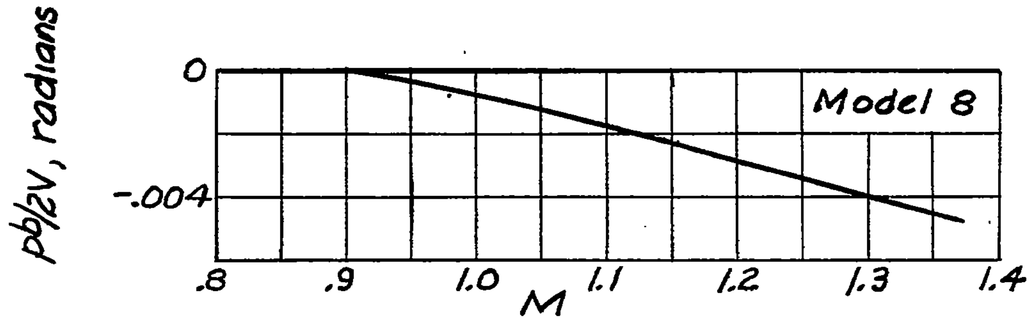


(b) Aspect ratio 4.5 and NACA 65-006 sections.

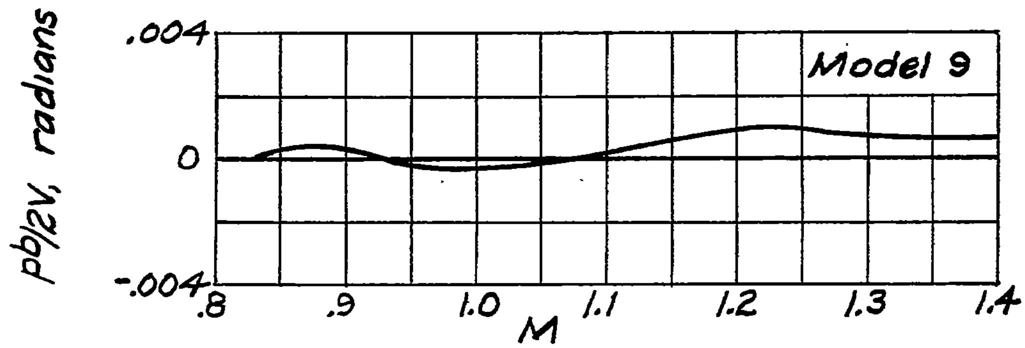


(c) Aspect ratio 3.7 and NACA 65A006 sections.

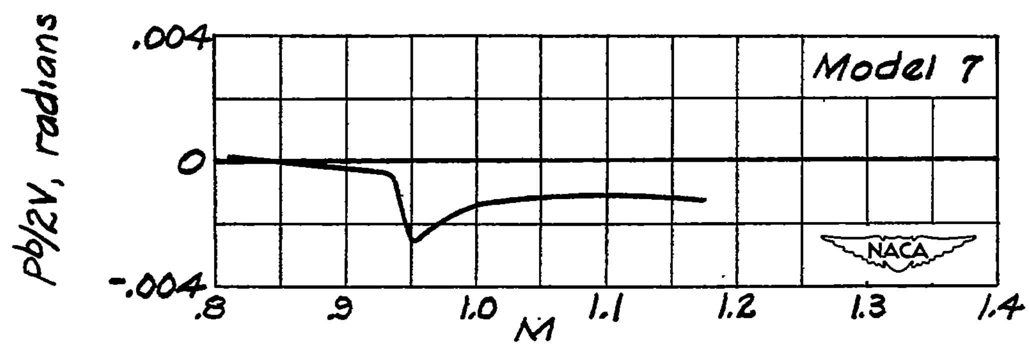
Figure 3.- Out-of-trim helix angles for models with straight nontapered wings 6 percent thick for various airfoil sections.



(a) Aspect ratio 3.7, sweep 45°, and NACA 65A006 sections.



(b) Aspect ratio 3.7, sweep 45°, and NACA 65A009 sections.



(c) Aspect ratio 3.7, sweep 30°, and NACA 65A009 sections.

Figure 4.- Out-of-trim helix angles for models with nontapered wings swept back 30° and 45° and NACA 65A006 and 65A009 airfoil sections.

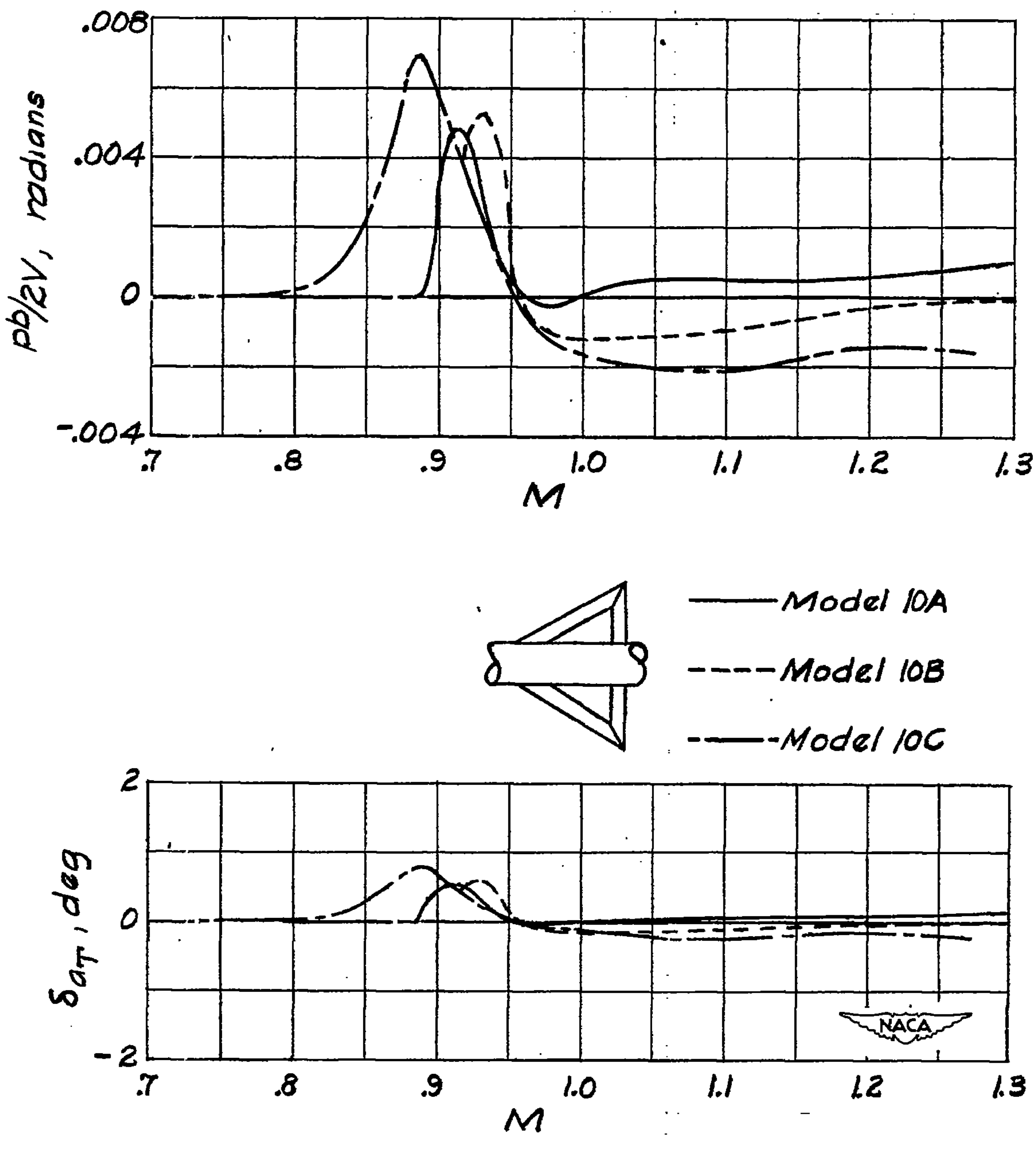


Figure 5.- Out-of-trim helix angles and trim aileron deflections required for models with 60° sweptback delta wings, aspect ratio 2.31, and hexagonal airfoil sections of constant thickness. (The values of δ_{a_T} are estimated for half-delta tip ailerons, reference 5.)

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